§4. Design Study of Magnets for Heliotron Type Fusion Reactor FFHR

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In the design of the helical type fusion reactor, the maximum magnetic field and the electromagnetic force of a helical coil are important factors. The miniaturization is preferable from the viewpoint of the construction cost. The larger device scale, however, has advantages that a necessary central toroidal field becomes lower to achieve the same Q value, and that it becomes easy to secure the installation space for blankets. Scale effects on superconducting magnet systems have been estimated under the conditions of a constant energy confinement time and the same aspect ratio. After that, a typical helical reactor is selected and the optimization of the coil support structure has been in progress.

In order to estimate scale effects on magnet systems, the energy confinement time τ_E is appropriate for the index of comparable reactors. The scaling low of ISS95 is adopted in this study. In the case that plasma heating power P per unit volume and an electron density n_e are constant, τ_E becomes

$$\tau_E^{ISS95} \propto a^{1.03} R^{0.06} B_0^{0.83} \qquad (1)$$

where a, R, and B_0 are a plasma minor radius, plasma major radius, and central toroidal field, respectively. Consequently, the necessary central toroidal field is in inverse proportion to the 1.31 power of the major radius under the conditions of the constant τ_E and a same aspect ratio.

The improvement factor for τ_E is set almost 2 in this study under the conditions of the center electron density of 30.4X1019 m-3 and center temperature of 15 keV. The estimated results are shown in Fig. 2 for the pitch number m of 8 and 10. The minimum space for blankets is derived by being subtracted by 0.1 m from the minimum gap between the helical coil and the last closed surface of the plasma for installing thermal shields. The current density j of the helical coil is set 25 MA/m^2. Since the required thickness of the blankets is considered to be more than 1 m for breeding tritium and shielding neutron, the smallest major radius is determined mainly by the space for blankets. The major radius around 15 m is necessary for a reactor similar to LHD. In order to realize more compact reactors, the lower aspect reactor with the equivalent confinement is promised.

Since the electromagnetic force on the helical coil is mainly in the minor radius direction, the necessary cross-section of coil support can be estimated from the integration of minor radius hoop force. As the results of estimation under the constant τ_E and the constant average stress, weight of the coil support is proportional to only the 0.37 power of the major radius. The influence of the radius on the construction cost of the magnet system will not be strong.

The optimization of the coil support structure has been carried out for the FFHR2m1, the major radius of which is enlarged to 14.0 m to improve the maintainability of blankets and to reduce the neutron wall load. A typical structural analysis example is shown in Fig.3. When the big port for maintenance is secured, the maximum stress is within 1,000 MPa.

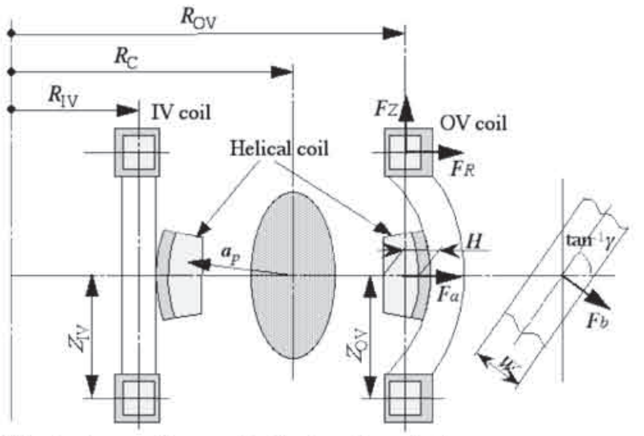

Fig. 1. A coordinate of helical coils and plasma

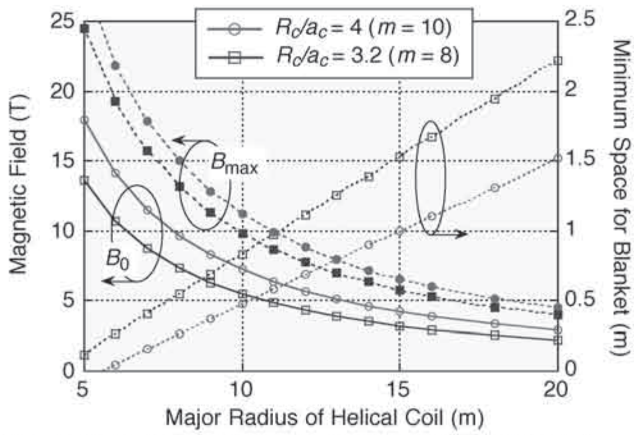

Fig. 2. Scale dependence of the central magnetic field B_0, the maximum magnetic field B_{max} and space for blankets under the conditions of τ_E= const., γ = 1.25, j=25 MA/m^2, W/H = 2, and S_m = 200 MPa.

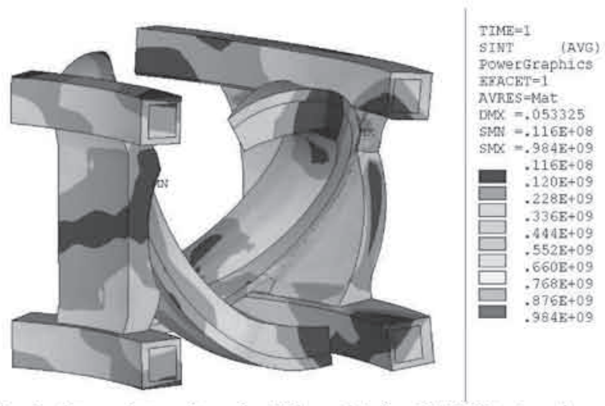

Fig. 3. Stress intensity of a FE model for FFHR2m1, where R_0 = 14.0 m, B_0=6.18 T, and γ = 1.15

Reference

1) S. Imagawa and A. Sagara, Plasma Science & Technology, Vol. 7, No.1 (February 2005) 2626-2628.